A NEW CONTROL PROTOCOL FOR HOME APPLIANCES - LnCP

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ABSTRACT

This paper proposes a new control protocol, LnCP(Living network Control Protocol), targeting at low implementation cost networking system in home environment. The protocol is based on multi-master system and uses a peer-to-peer communication model. The protocol assumes single bus therefore the appliances can be attached to the bus anywhere if the power lines are employed as network bus. Home appliances linked via LnCP are controlled and monitored at remote place. Every device communicates with each other in packet unit, which has variable length so that the protocol can deal with the devices having the diverse room of RAM resource. The bytes number of packet header is also variable in order that new function can be added in the future.

The minimum hardware requirements to implement the protocol are 8-bit processing microcomputer including built-in UART, 17 bytes of volatile memory and few bytes of non-volatile memory. Therefore it may be embedded in low-cost microcontrollers that are employed in the white goods such as refrigerator, washing machine, micro oven range and even light switch.

1. INTRODUCTION

There are so many attempts to maintain some degree of standardization for home automation applications. For example the X10, LonTalk and CEBus standards define the communication protocols, interface standards and other technical aspects. Although the X10 [2] has been around since the 1970's it is typically suited for simple on/off control that is a misconception about what the home automation actually is. The CEBus[1] have been developed with the purposes of home automation applicable to all home appliances such as TV, Audio, Video, refrigerator and even light lamp. As the result the generality is guaranteed in parts and it gives manufacturers the chance to make network devices without developing any application protocols. LonTalk[3] was designed for communication in control network so that the it is characterized by short message and low speed. However the standardizations that many companies have pursued until now may cause following two basic problems.

- Heavyweight level application in viewpoint of microcontroller employed by white goods.
- High implementation cost because of additional communication module.

These problems are explained as follows. Home appliances can be classified into three subnets according to the communication speed and the amounts of transmitting data. The first subnet is consists of multimedia appliances like TV, Video and Audio, which deal with mainly image data. The second subnet is structured with PC and peripheral devices such as printer, fax, and scanner. The third subnet is made up of white goods, which need to control, monitor the state of appliance and load small size of data. We call those by AV-net, PC-net and living-net for convenience respectively. The appliances belonging to each subnet have broad spectrum in the cost and function aspects. Existing protocols support the services and maintenance not only on specific subnet but also on home network integrating all subnets. And also the protocols do not consider implementation with microcontroller of appliance but requires the additional communication module. Therefore these lead to heavyweight protocol because there must be networking and routing mechanism, and that there must be interpreter of common language like CAL in CEBus. Therefore in the viewpoint of controller's capability it is difficult to implement for white goods that employ 8-bit processing microcomputer at most. As far as the white goods use low-speed microcomputer because of the limitation of acceptable price the end-user must possess additional communication module where most layers of the protocol are implemented for each appliance.

To overcome above problems cost-effective and appliance-oriented protocol, LnCP(Living network Control Protocol), is proposed. The proposed protocol is simple and it is sufficiently implemented in existing white goods without additional communication module if they operate with 8-bit processing microcontroller. This paper focuses on the concepts of LnCP as a low cost solution for home networking and therefore the detail specifications are not described.

Section 2 introduces how to construct network via LnCP, and section 3 for the concepts and layering. In section 4 the packet structure is presented, while the communication architecture using this packet is described in section 5. Section 6 deals with the message that is a language to control appliances. Finally, summarize the features of LnCP in section 7.

2. OVERVIEW OF LnCP

2.1. Living Network and its concepts

The network is constructed by linking appliances, which implement the LnCP on their microcontroller, via a networking bus. Some appliances that do not have micorocontroller are combined with a module, which contains LnCP and enables them to be networked, as shown in Figure 1. Single wire or power lines are the candidates for the medium as networking bus. If power line is used as medium then each appliance must connect to power line transceiver, whose encoding method is not defined in LnCP. Any appliance or the combination of appliance and a module, which is attached to the bus on the network, is referred to as a node. The network interface must ensure that each node has half duplex communications, and can sense activity on the network.
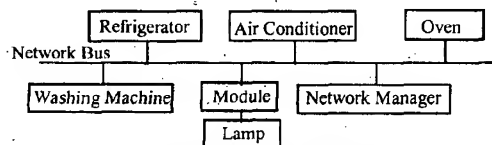

Figure 1: Network Structure

The LnCP allows any node on the bus to communicate with and control any other node in living network. Even the LnCP introduce the network management device to interface with user through keyboard and screen, there is no central control device. Consequently there is no hierarchy on product-to-product communications. LnCP covers only the node communication protocol; the protocol intended for home appliances in living network. It does not cover the Router communications protocol.

Since LnCP allows communication of a variety of data types, from simple control commands, to more complex information such as image data and program code, the networked appliances can provide the user the following functions:
• Control : Control the appliances on/off or variable power.
• Monitoring : Monitor the operating state and sensor of appliances.

• Automation : Automatic control between devices without user operating.
• Download : Upgrade the software in microcontroller to enhance the basic functions or add new functions.

2.2. Protocol Layers

The protocol is based on the ISO Open Systems Interconnect(OSI) seven layers network protocol model. LnCP layering consists of the Physical Layer, Data Link Layer and Application Layer. Each layer follows the divisions established by the OSI standard for protocol tasks. The layering is described below.

Physical Layer is responsible for data encoding and decoding. Although LnCP does not define this layer the LnCP use UART as a default encoding method for the simplicity of implementation because many microcontrollers have the built-in UART adapter and PC also provide that service. Data Link Layer(DLL) is divided into MAC(Medium Access Control) layer and Link layer. MAC employs collision avoidance algorithm. Link layer handles reception of packets over the attached medium, address recognition, error detection, packet timing, packet retransmission and detection of the duplicate message. Application Layer is responsible for message generation, message reception, message execution and message fragmentation.

3. KEY FEATURES OF LnCP

The LnCP is based on the multi-master system. Accordingly every product can be classified into two categories, master and slave. Master is that sends slave a message to begin conversation when any event is generated by user or some algorithm and has total control over the network for the duration of that communication. It is noted that the master is not in the state of "listening" if he did not make a conversation with other devices. Slave responds to the master's request. If there is no any request from other devices the slave has to listen to network bus. According to definitions product-to-product communication is only enabled by master and is only accomplished between master and slave. The communication between masters cannot be accomplished.
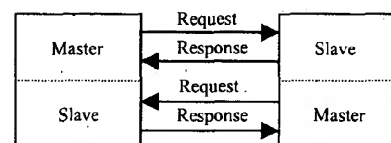

Figure 2. Structure of P2P device

To enable actual peer-to-peer communications, LnCP defines a new device, named P2P device. P2P device is defined as the device having logical LnCP compliant master and slave as in Figure 2. That is to say, the P2P device acts as slave normally and as master when any event is generated. The device name, P2P, means that the "peer-to-peer" communication is possible. The introduction of P2P device gives the developer following three benefits. The first is that it is sufficient to develop the networked appliance enabling product-to-product communication by only understanding the master-slave communication mechanisms. Secondly, in viewpoint of software engineer it is easy to program the communication algorithm because the device is divided into two logical devices that perform different tasks independently. Thirdly, the developer can make a decision easily to eliminate optional communications mechanisms considering the disturbance to basic functions such as washing, cooking and heating.

Although each layer represents a division of responsibility of the protocol and can be implemented independently, all layers share the same memory for buffering to minimize use of RAM. This is a result of taking into consideration of actual situation in white goods, which employs generally the 8-bit processing microcontroller that has the small size of RAM. Since the LnCP is implemented in microcontroller that have also basic functions, it is difficult to assign much memory for communications. Thanks to the half duplex communication stated above the receiving and transmitting tasks also can share the same memory if the device acts as master or slave. This restriction on memory use leads to cost-effective and easy-to-use protocol for appliance developers in that the protocol must have the simple communication architecture. In case of P2P device, even if it were half duplex communication, the memory for logical master to transmit has to be divided from shared buffer because it needs the memory to keep for retransmission until the transmitting process is completed.

• Master and slave : Use a memory array to receive and transmit in Data Link and Application Layers.
• P2P device : Use a memory array for master to transmit in Data Link and Application Layers. And an additional memory array for slave to receive and transmit, for master to receive in Data Link and Application Layers.

The LnCP uses a connectionless service protocol. This means that devices gain access to the network bus only long enough to transmit a message and then get off[2]. No connection is formed between two devices to communicate, tying the network up during their conversation. To share the bus among many devices the protocol provides short messages limited to 255 bytes and defines the minimum delay time between packet transmissions.

4. PACKET STRUCTURE

Since LnCP does not define the requirements for the Physical Layer in detail the signal frame on the medium is also not defined. Therefore the protocol defines only the packet to communicate on a peer-to-peer basis with Data Link Layer. Each packet is made up of a header, a body and a trailer. Header, body and trailer contain the communication, control, and error detection information respectively.

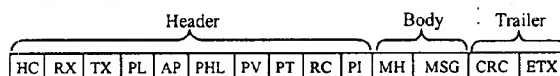| Header										Body		Trailer	
HC	RX	TX	PL	AP	PHL	PV	PT	RC	PI	MH	MSG	CRC	ETX

Figure 3: Packet structure

HC : Home Code(8bit), Rx: Receiver Address(16bit),
Tx : Sender Address(16bit), PL : Packet Length(8bit),
AP : Access priority(3bit), PHL : Packet Header Length(5bit),
PV : Protocol Version(9bit), PT : Packet Type(4bit),
RC : Retransmission Count(2bit), PI: Packet Identification(2bit),
MH : Message Header, MSG : Message,
CRC : Cyclic redundancy check(16bit), ETX : 8bit

5. LINK LAYER

When packet data are received from other device, the Data Link Layer investigates recipient address, packet type, protocol version and bit error with the information of header and trailer. If there is not any error in packet data that layer hand the body data over Application Layer. When body data are received from *Application Layer, the* Data Link Layer structures a packet, controls the communication process and that passed the packet data to MAC layer.

5.1. Addressing

In LnCP the sender designates the recipient using home code and address. HC indicates identifies home code and

Physical address(8bit)	Logical address(8bit)	
Product code	Device address	
	Area code	

Figure 4. The structure of address field

Product name	Product code	Address range
Network manager	0x00	- .
Refrigerator	0x01	0x0100~0x01FE
Air conditioner	0x02	0x0200~0x02FE
Washing machine	0x03	0x0300~0x03FE
:	:	:

is useful for differentiating the house from neighbors when many houses share the same medium like the power line. RX and TX identify the addresses of the recipient and transmitting devices, respectively. The first byte in the address field is product code, which is assigned with a unique value identifying the basic function of residential products and has nothing to do with the vender. Even there is a little difference in functions between two types of product, for example washing machines operating with pulsator and drum, the products have the same codes. This code is predefined by LnCP and stored in ROM and hence physical address, which differs from serial number in Ethernet card in that all refrigerators over the world have the same value. The second byte is the logical address to classify the devices having the same product code. The logical address may be device address or area code. Device address is used for addressing the appliances having the same name. Area code is allocated according to the installed area in home. Home code and logical address are stored in non-volatile memory such as EEPROM and flash ROM.

Group address is assigned as all bits in each subfield are set to "1". For example, 0x01XX indicates the group address of refrigerators, where XX means "don't care". 0x3FXX is a group address indicating all appliances that have the same area code. Because the grouping logic in LnCP is oriented to home environment it is very powerful for home automation.

5.2. Transport Protocol

The transport protocol use PT and RC values. LnCP defines three types of packet, that is, request packet, response packet and notification packet. Request packet is transmitted from master to control or get the information of slave. Response packet is transmitted from slave to respond to the master's request. And response packet is divided into successful response packet, which includes
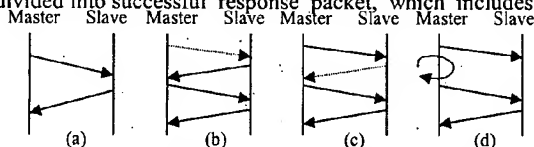

Figure 6. Protocol diagram for retransmission

Solid line : Normal transmission, Dotted line : bit error, Circle : waiting
(a)Normal conversation
(b)Retransmission when bit error in request packet
(c)Retransmission when bit error in response packet
(d)Retransmission when no response packet.

ACK message or NAK message, and failed response packet, which must include NAK message. When the master receives the failed response packet it can retransmit the original packet three times at maximum. If there is any bit error with received request packet then the slave transmits the failed response packet. Otherwise the slave transmits the successful response packet even though the message is not executed successfully because of an error with arguments in message, duplicate message reception and so on. Notification packet is transmitted from master and the recipients do not respond to that.

Using the above packets the protocol makes three types of conversation in point of master view as follows.

- 1-request and 1-response : it is a normal conversation between 1-master and 1-slave. Master terminates the conversation when it receives a successful response packet or when there is no response within maximum waiting time.
- 1-request and multiple-response : it is the case of using group address as the recipient. Master continues to receive the response until the maximum waiting time elapse. There is no retransmission.
- 1-notification : it is an one-sided conversation.

To control these conversations master uses RC value. The master increments the RC value by 1 whenever it retransmits the original packet. The initial value is 1 and the maximum value is 3. For the slave cannot control the conversation it always sets RC value to 1. The master retransmits the packet when it is elapsed the maximum waiting time after sending a request packet as well as when he received a failed response packet. To keep the protocol performance in network environment the slave discards the reception of response packet.

5.3. Error Detection

Each layer has its own error detection mechanism to minimize the probability of malfunction. The Link Layer utilizes a 16 bit cyclic redundancy check(CRC). The 16 bit CRC can detect all single/double bit errors, all errors with odd bits, and burst errors of length <16, with 99.997% accuracy. And the simulation result yields a maximum of only one undetected error in 1,000,000 faulty packets[4].

5.4. The others

PL length defines the number bytes within the packet including HC and ETX. The packet length is variable and the value depends on the lengths of header and message. Each appliance defines the PL in consideration of

available memory in range of 17 to 255. PHL is the length of packet header form HC to PN. Its value is in the range of from 9 to 32 bytes such that the new functions can be added to upgrade the compatible protocol with the lower version. PV means the protocol version.

PI is the packet identification and the sender increments its value by 1 whenever it transmits a new packet except that it retransmits. The value is reset to 0 when the device is rebooted or when the transaction count has reached its maximum value. The PN fields are combined to RC value to investigate the duplicate packet and hence the same bit length with the RC field.

AP controls the priority of access to the medium and is assigned to each transmitted packet. It is used to determine how soon it can contend for medium access after the last packet in MAC layer.

6. APPLICATION LAYER

As described in previous section there is no the information about the message segmentation into several shorter messages and message reassembly. The LnCP assigns that task to the Application Layer because of the following reason. It is due to sharing the buffering memory by Data Link Layer and Application Layer. Two layers support packet payload up to the same bytes in length, which depends on the size of memory available for the messaging buffer. Eventually the tasks dealing with long message is performed in Application Layer by defining the variable-sized message.

6.1. Message

A message in this paper is defined as a set of elements that have information to control the communication process and analyze the results of that in the point of master view. Message is divided into two categories according to the type of device who makes a message, request and response messages.

Request message includes the command and the arguments to execute it. There are two kinds of response message, ACK and NAK messages. The response messages include the copy of command code, ACK/NAK and return arguments generated after execution of command code. The bytes number of the each argument is fixed definitely to each command code.

$Message = \{\{ Request\ message\}, \{ Response\ message\}\}$

$= \left\{ \begin{array}{l} \{ Command\ code,\ Input\ arguments\}, \\ \{\{ Command\ code\ copy,\ ACK,\ Return\ arguments\}, \\ \{ Command\ code\ copy,\ NAK,\ Error\ code\} \end{array} \right\}$

Message field is characterized by message header that contains the message length(ML), message header length(MHL) and port number(PN). ML is the value MHL plus the bytes number of message field.

MHL is the bytes number from ML field to the byte just before message field. Owing to variable PHL and MHL fields the message header defined above is extensible. For example, the Application layer can specify whether data should be transmitted with or without security adding that field in message header. PN allows the various application languages for Application Layer in spite of LnCP has its own language.
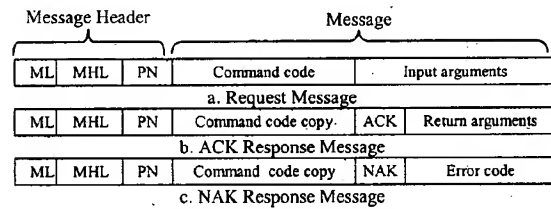
Message Header			Message		
ML	MHL	PN	Command code		Input arguments

a. Request Message

ML	MHL	PN	Command code copy	ACK	Return arguments

b. ACK Response Message

ML	MHL	PN	Command code copy	NAK	Error code

c. NAK Response Message

Figure 7. Message Structure

ML : Message Length(8bit), MHL : Message Header Length(8bit), PN : Port Number(8bit)

6.2. Message Set

LnCP classifies the message into common and appliance specific sets. The common set is also divided into network management messages and product operating messages such as control of user interface and memory. Each message set classified above has also optional and required messages.

The purpose of the message in LnCP focuses mainly on the control or monitoring of the home appliances. Therefore the bytes number of message is generally very short(under 10bytes) and is predetermined according to specific functions, of which name is fixed-length message. Consequently there is no necessity to segment and

Message name	Power control	
Command code	0x05	
	Name	Data type
Input arguments	Power value	unsigned char
Return arguments	-	-
Comments	"Power value" is in range of 0 to 255. 0 means "off" and 255 means "on" with full power	

Figure 8. An example of fixed-length message

Message name	Write memory	
Command code	0x81	
	Name	Data type
Input arguments	Memory type	unsigned char
	Total message no.	unsigned short int
	Message no.	unsigned short int

	Start address	unsigned long
	Byte no.	unsigned char
	Data unit	unsigned char
	Data	unsigned char [ ]
Return arguments	-	-
Comments	"Memory type" is EEPROM(0), 8-bit memory(1) or 16-bit memory(2).	

Figure 9. An example of variable-length message

reassemble for this message provided that the microcontroller has the sufficient memory to buffer such message data. Figure 8 is an example of fixed-length message of power control in C language expression. In this case the length of message field is 2.

Contrary to fixed-length message variable-length message handles long message such as image data and programming code. This message is segmented into enough shorter messages to store in the available memory, accordingly it has to contain the variable implying the packet number as input arguments. Figure 9 is the examples of the variable-length message. In this case the maximum length(N) of data fragmented is given as follows.

$$N = PL - PHL - MHL - 3 - 11,$$

where 11 means the bytes number of input arguments except data array.

Owing to calculation of the argument values with each segmented message it seems to be somewhat complex to handle the variable-length message but not for the fixed-length message. Furthermore the variable-length message is used for upgrading the contents of memory such as image file or new program codes. It is therefore definite that only the high-end device like PC uses the variable-length message in request packet, while most appliances, which do not have convenient user interface sufficient to handle the above tasks, only use the fixed-length message even if it act as master. In other word, there is no necessity to deal with long message and hence very simple to implement the protocol in case of white goods. This is one of the key concepts of the LnCP focusing on implementation in existing microccontroller with low cost.

Error code in Figure 7 is also similar in classification to the message set. While the common error codes include the bit error in packet, bad command and illegal arguments, the appliance specific error codes are relate to faults or troubles during operation. The detail specification is out of scope to touch in this paper.

7. SUMMARY AND COMMENTS

A new control protocol for home appliances has been proposed. The main advantage of the proposed protocol is to build a network at very low cost in home environment.

The protocol is simple and easy-to-use for developer, while there is no limitation to construct home network. The minimum requirements for the system are listed below.

- 8-bit processing microcomputer
- Built-in UART(half-duplex or full-duplex)
- 17 bytes of RAM
- Few bytes of non-volatile memory
- Under 2 Kbytes of ROM
-

Some parts of the protocol developed has been tested and applied to mass-production. Work is now continuing on the development of network management protocol, encryption algorithm, and on the development of software connecting to external network such as Internet.

8. REFERENCES

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